CLAIMS

1. An ultrasonic probe comprising an elongate body having a first end and a second end, an ultrasonic transducer attached to the probe at or adjacent the first end, and an enlarged support section intermediate the ultrasonic transducer and the second end, wherein the enlarged support section has an equivalent diameter greater than an equivalent diameter of the body at any location between the enlarged support section and the ultrasonic transducer.

2. The probe of Claim 1 wherein the ultrasonic transducer is a piezoelectric transducer or a magnetostrictive transducer.

3. The probe of Claim 1 wherein the ultrasonic transducer is a magnetostrictive transducer formed by an electrical coil wrapped around a section of the probe between the first end and the enlarged support section.

4. The probe of Claim 1 comprises a metal or metal alloy.

5. The probe of Claim 1 wherein the probe has a circular cross section at any location between the first end and the second end, the cross section being defined as a section perpendicular to an axis defined by the first end and the second end.

6. The probe of Claim 5 wherein at least a portion of the probe between the enlarged support section and the second end is cylindrical, and wherein the diameter of the probe decreases discontinuously in this portion.

7. The probe of Claim 5 wherein the probe has a circular cross section at all locations between the enlarged support section and the second end, and wherein the diameter of the probe decreases continuously between the enlarged support section and the second end.

8. The probe of Claim 1 wherein the ratio of the distance between the first end and the enlarged support section to the distance from the enlarged support section to the second end is between 1:10 and 10:1

9. The probe of Claim 1 which further comprises a detachable tip attached to the second end of the probe.

10. An ultrasonic probe comprising an elongate body having a first end and a second end, an ultrasonic transducer attached to the probe at or adjacent the first end, a cylindrical collar support section intermediate the ultrasonic transducer and the second end, wherein the probe is cylindrical between the first end and the collar support section, and wherein the collar support section has a diameter greater than diameter of the cylinder between the collar support section and the ultrasonic transducer.

11. An ultrasonic probe comprising

(a) an elongate planar body having a first end, a second end opposite the first end, a third end intersecting the first and second ends, a fourth end opposite the third end and intersecting the first and second ends, a first side intersecting the first, second, third, and fourth ends, and a second side opposite the first side and intersecting the first, second, third, and fourth ends;

(b) attachment means on the first end adapted for attaching the first end to one or more transducer assemblies;

(c) a first longitudinal shoulder support section projecting from the first side, extending linearly between the third and fourth ends, and having an outer edge; and

(d) a second longitudinal shoulder support section projecting from the second side, extending linearly between the third and fourth ends, and having an outer edge, wherein the second longitudinal shoulder support section is disposed opposite the first longitudinal shoulder support section;

wherein the distance between the outer edge of the first longitudinal shoulder support section and the outer edge of the second longitudinal shoulder support section is greater

than the thickness of the planar body at any location between the longitudinal shoulder supports and the first end, the thickness of the planar body being defined as the perpendicular distance between the first and second sides.

12. An ultrasonic probe assembly comprising

(a) a seal assembly comprising a seal body having a first end and a second end, an axis passing through the first end and the second end, and a coaxial cylindrical passage within the seal assembly between the first end and the second end;

(b) An ultrasonic probe comprising an elongate body having a first end and a second end, an ultrasonic transducer attached to the probe at or adjacent the first end, and a cylindrical collar support section intermediate the ultrasonic transducer and the second end, wherein the probe is cylindrical between the ultrasonic transducer and the collar support section, the collar support section has a diameter greater than diameter of the cylinder between the collar support section and the ultrasonic transducer, the cylindrical section of the probe is disposed coaxially within the cylindrical passage of the seal body such that the shoulder support section is adjacent the second end of the seal body, and the diameter of the cylindrical shoulder section is greater than the diameter of the cylindrical passage at the second end of the seal body; and

(c) an elastomeric torroidal seal ring disposed coaxially between the collar support section of the ultrasonic probe and the second end of the seal body.

13. The ultrasonic probe assembly of Claim 12 wherein the cylindrical section of the ultrasonic probe extends beyond the first end of the seal body and wherein the ultrasonic probe assembly further comprises a compression fitting adapted to grip the ultrasonic probe and the first end of the seal body to maintain the ultrasonic probe in a coaxial position in the cylindrical passage of the seal assembly.

14. The ultrasonic probe assembly of Claim 12 wherein the ultrasonic probe comprises a metal or metal alloy.

15. The ultrasonic probe assembly of Claim 12 wherein the seal body comprises a metal or metal alloy.

16. The ultrasonic probe assembly of Claim 12 wherein the elastomeric torroidal seal ring comprises an elastomer selected from the group consisting of tetrafluoroethylene, chlorotrifluoroethylene, polyvinylidene fluoride, perfluoroalkoxy, polyethylene, unplasticized polyvinyl chloride, acrylonitrile butadiene styrene, acetal, cellulose acetate butyrate, nylon, polypropylene, polycarbonate, polyphenylene oxide, polyphenylene sulfide, polysulfone, polyamide, polyimide, thermosetting plastic, natural rubber, hard rubber, chloroprene, neoprene, styrene rubber, nitrile rubber, butyl rubber, silicone rubber, chlorosulfonated polyethylene, polychlorotrifluoroethylene, polyvinyl chloride elastomer, cis-polybutadiene, cis-polyisoprene, ethylene-propylene rubbers, carbon, and graphite.

17. The ultrasonic probe assembly of Claim 13 wherein the compression fitting includes a torroidal elastomeric ferrule comprising an elastomer selected from the group consisting of tetrafluoroethylene, chlorotrifluoroethylene, polyvinylidene fluoride,perfluoroalkoxy, polyethylene, unplasticized polyvinyl chloride, acrylonitrile butadiene styrene, acetal, cellulose acetate butyrate, nylon, polypropylene, polycarbonate, polyphenylene oxide, polyphenylene sulfide, polysulfone, polyamide, polyimide, thermosetting plastic, natural rubber, hard rubber, chloroprene, neoprene, styrene rubber, nitrile rubber, butyl rubber, silicone rubber, chlorosulfonated polyethylene, polychlorotrifluoroethylene, polyvinyl chloride elastomer, cis-polybutadiene, cis-polyisoprene, ethylene-propylene rubber, carbon, and graphite.

18. The ultrasonic probe assembly of Claim 12 which further comprises a transducer assembly attached to the first end thereof.

19. An ultrasonic processing system comprising

(a) An ultrasonic probe assembly including

(1) a seal assembly comprising a seal body having a first end and a second end, an axis passing through the first end and the second end, and a coaxial cylindrical passage disposed between the first end and the second end;

(2) An ultrasonic probe comprising an elongate body having a first end and a second end, an ultrasonic transducer attached to the probe at or adjacent the first end, and a cylindrical collar support section intermediate the ultrasonic transducer and the second end, wherein the probe is cylindrical between the ultrasonic transducer and the collar support section, the collar support section has a diameter greater than diameter of the cylinder between the collar support section and the ultrasonic transducer, the cylindrical section of the probe is disposed coaxially within the cylindrical passage of the seal body such that the shoulder support section is adjacent the second end of the seal body, and the diameter of the cylindrical shoulder section is greater than the diameter of the cylindrical passage at the second end of the seal body; and

(3) an elastomeric torroidal seal ring disposed coaxially between the collar support section of the ultrasonic probe and the second end of the seal body;

(b) a pressure vessel having an interior, an exterior, and at least one opening between the interior and the exterior; and

(c) first sealing means associated with the second end of the seal assembly and second sealing means associated with the at least one opening in the pressure vessel, wherein the first and second sealing means are adapted to form a seal between the seal assembly and the pressure vessel;

wherein the elastomeric torroidal seal ring is compressed between the collar support section and the second end of the seal body to form a seal between the interior and the exterior of the pressure vessel, and wherein the second end of the ultrasonic probe is disposed in the interior of the pressure vessel.

20. The ultrasonic processing system of Claim 19 wherein the cylindrical section of the ultrasonic probe extends beyond the first end of the seal body and wherein the ultrasonic probe assembly further comprises a compression fitting adapted to grip the ultrasonic probe and the first end of the seal body to maintain the ultrasonic probe in a coaxial position in the cylindrical passage of the seal assembly.

21. The ultrasonic processing system of Claim 19 wherein the ultrasonic probe assembly further comprises a transducer assembly attached to the first end thereof.

22. The ultrasonic processing system of Claim 19 wherein the pressure vessel further comprises an inlet for introducing a fresh cleaning fluid into the pressure vessel and an outlet for withdrawing a contaminated cleaning fluid from the pressure vessel.

23. The ultrasonic processing system of Claim 19 wherein the pressure vessel further comprises an inlet port for introducing one or more contaminated articles into the pressure vessel and an outlet port for withdrawing one or more cleaned articles from the pressure vessel.

24. A method of providing ultrasonic energy to a pressurized fluid comprising

(a) providing an ultrasonic pressure vessel system including

(1) an ultrasonic probe assembly including

(1a) a seal assembly comprising a seal body having a first end and a second end, an axis passing through the first end and the second end, and a coaxial cylindrical passage disposed between the first end and the second end;

(1b) An ultrasonic probe comprising an elongate body having a first end and a second end, an ultrasonic transducer attached to the probe at or adjacent the first end, and a cylindrical collar support section intermediate the ultrasonic transducer and the second end, wherein the probe is cylindrical between the ultrasonic transducer and the collar support section, the collar

support section has a diameter greater than diameter of the cylinder between the collar support section and the ultrasonic transducer, the cylindrical section of the probe is disposed coaxially within the cylindrical passage of the seal body such that the shoulder support section is adjacent the second end of the seal body, and the diameter of the cylindrical shoulder section is greater than the diameter of the cylindrical passage at the second end of the seal body; and

(1c) an elastomeric torroidal seal ring disposed coaxially between, and forming a seal between, the collar support section of the ultrasonic probe and the second end of the seal body;

(2) a pressure vessel having an interior, an exterior, and at least first and second openings between the interior and the exterior; and

(3) first sealing means associated with the second end of the seal assembly and second sealing means associated with the first opening in the pressure vessel, wherein the first and second sealing means are adapted to form a seal between the seal assembly and the pressure vessel, wherein the elastomeric torroidal seal ring is compressed between the collar support section and the second end of the seal body to form a seal between the interior and the exterior of the pressure vessel, and wherein the second end of the ultrasonic probe is disposed in the interior of the pressure vessel;

(b) introducing a pressurized fluid via the second opening into the interior of the pressure vessel;

(c) providing electrical power to the ultrasonic transducer to generate ultrasonic energy; and

(d) transmitting the ultrasonic energy through the ultrasonic probe to the pressurized fluid in the interior of the pressure vessel.

25. The method of Claim 24 wherein the pressure of the pressurized fluid in the interior of the pressure vessel is in the range of 10^{-3} to 680 atma.

26. The method of Claim 24 wherein the ultrasonic energy is provided in a frequency range of 20 KHz to 2 MHz.

27. The method of Claim 24 wherein the ultrasonic energy is provided at a power density in the range of 0.1 to 10,000 W/in^2.

28. The method of Claim 24 wherein the pressurized fluid comprises one or more components selected from the group consisting of carbon dioxide, nitrogen, methane, oxygen, ozone, argon, hydrogen, helium, ammonia, nitrous oxide, hydrogen fluoride, hydrogen chloride, sulfur trioxide, sulfur hexafluoride, nitrogen trifluoride, monofluoromethane, difluoromethane, tetrafluoromethane, trifluoromethane, trifluoroethane, tetrafluoroethane, pentafluoroethane, perfluoropropane, pentafluoropropane, hexafluoroethane, hexafluoropropylene, hexafluorobutadiene, octafluorocyclobutane, and tetrafluorochloroethane.

29. The method of Claim 28 wherein the pressurized fluid further comprises one or more processing agents selected from a group consisting of an acetylenic alcohol, an acetylenic diol, a dialkyl ester, hydrogen fluoride, hydrogen chloride, chlorine trifluoride, nitrogen trifluoride, hexafluoropropylene, hexafluorobutadiene, octafluorocyclobutane tetrafluorochloroethane, fluoroxytrifluoromethane (CF_4O), bis(difluoroxy)methane (CF_4O_2), cyanuric fluoride ($C_3F_3N_3$), oxalyl fluoride ($C_2F_2O_2$), nitrosyl fluoride (FNO), carbonyl fluoride (CF_2O), perfluoromethylamine (CF_5N), an ester, an ether, an alcohol, a nitrile, a hydrated nitrile, a glycol, a monester glycol, a ketone, a fluorinated ketone, a tertiary amine, an alkanolamine, an amide, a carbonate, a carboxylic acid, an alkane diol, an alkane, a peroxide, a water, an urea, a haloalkane, a haloalkene, a beta-diketone, a carboxylic acid, an oxine, a tertiary amine, a tertiary diamine, a tertiary triamine, a nitrile, a beta-ketoimine, an ethylenediamine tetraacetic acid and derivatives thereof, a catechol, a choline-containing compound, a trifluoroacetic anhydride, an oxime, a dithiocarbamate, and combinations thereof.

30. The method of claim 28 which further comprises providing a sealable opening in the pressure vessel adapted to insert and withdraw one or more articles, inserting one or more contaminated articles into the pressure vessel prior to (b), cleaning the one or more contaminated articles during (c) and (d), depressurizing the pressure vessel by withdrawing a contaminated fluid therefrom, and withdrawing one or more cleaned articles therefrom.

31. The method of Claim 24 wherein the fluid comprises at least one component which undergoes a chemical reaction that is promoted by the ultrasonic energy introduced into the pressure vessel.

32. The method of Claim 24 wherein the shoulder support section of the ultrasonic probe is located at a vibrational node between the first and second ends of the ultrasonic probe.

33. A method for cleaning a contaminated wafer comprising:

(a) providing an ultrasonic pressure vessel system including

(1) an ultrasonic probe assembly including

(1a) an elongate planar body having a first end, a second end opposite the first end, a third end intersecting the first and second ends, a fourth end opposite the third end and intersecting the first and second ends, a first side intersecting the first, second, third, and fourth ends, and a second side opposite the first side and intersecting the first, second, third, and fourth ends;

(1b) attachment means on the first end adapted for attaching the first end to one or more transducer assemblies;

(1c) a first longitudinal shoulder support section projecting from the first side, extending linearly between the third and fourth ends, and having an outer edge; and

(1d) a second longitudinal shoulder support section projecting from the second side, extending linearly between the

third and fourth ends, and having an outer edge, wherein the second longitudinal shoulder support section is disposed opposite the first longitudinal shoulder support section;

wherein the distance between the outer edge of the first longitudinal shoulder support section and the outer edge of the second longitudinal shoulder support section is greater than the thickness of the planar body at any location between the longitudinal shoulder supports and the first end, the thickness of the planar body being defined as the perpendicular distance between the first and second sides;

(2) a reactor vessel having an interior, an exterior, and at least first and second openings between the interior and the exterior; and

(3) first sealing means associated with the first and second longitudinal shoulder support sections and second sealing means associated with the first opening in the pressure vessel, wherein the first and second sealing means are adapted to form a seal between the ultrasonic probe and the pressure vessel, wherein the second end of the ultrasonic probe is disposed in the interior of the pressure vessel;

(b) introducing the contaminated wafer into the interior of the pressure vessel;

(c) introducing a pressurized fluid via the second opening into the interior of the pressure vessel, thereby pressurizing the vessel;

(d) providing electrical power to the ultrasonic transducer to generate ultrasonic energy; and

(e) transmitting the ultrasonic energy through the ultrasonic probe to the pressurized fluid in the interior of the pressure vessel while moving the wafer past the second end of the ultrasonic probe.

34. The method of Claim 33 wherein the wafer defines a first plane and the ultrasonic probe defines a second plane, and wherein the included angle between the first plane and the second plane is between 10 degrees and 90 degrees.